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EUV AIM tool design study

ESTIMATED COSTING OF AN EUV MASK INSPECTION MICROSCOPE

Report 4 for
AIM Design Study

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DISCLAIMER

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1 Context of this report

This document is the fourth sub-report of the EUV AIM design study being conducted at LLNL on behalf of International SEMATECH (ISMT) and addresses the issue of preliminary system costing.

The purpose of the LLNL study, as identified in section 1.2 of the statement of work, is to research the basic user requirements of an actinic defect characterisation tool, potential design configurations and top-level specifications. The objectives of this design study specifically identified in section 1.3 of the statement of work were to

1. Determine the user requirements of an actinic defect characterisation tool
2. Determine if an EUV AIM tool is an appropriate platform for actinic defect characterisation
3. Determine possible design configurations and top-level performance specifications
4. Identify potential technical issues and risks of different technical approaches
5. Provide estimates of cost relating to different technical approaches; and
6. Provide simulated performance for key subsystems and the entire system

The sub-sections of the study to be addressed were accordingly defined in the statement of work as being:

1. Formulation of top-level specifications
2. Identification of system configurations suitable for meeting the top-level specifications
3. Preliminary design of imaging systems
4. Preliminary design of illumination systems
5. Prediction and comparison of performance through aerial image calculation
6. Identification of sub-system requirements
7. Identification of potential vendors
8. Estimation of system cost
9. Identification of technical issues
10. Definition of technology transfer or development required

Points 1 to 7 and 9 to 10 are addressed in separate reports to ISMT. This report addresses item 8, system costing, and is provided as a separate report so that its content can be kept confidential at the discretion of ISMT.

In this analysis we cost two systems – one based on normal-incidence multilayer-coated optics and another based on zone plate optics. The costing of these two systems are provided separately because the fabrication costs and technical challenges associated with each approach are different in areas relating to optics fabrication, and are highlighted by providing separate costing for the two approaches.

2 Notes on the costing

The costing has been divided into four separate sections:

System design and infrastructure costs details design and infrastructure costs specific to completing the first unit, but which can be re-used for the manufacture of subsequent units. This includes, for example, system design, the cost of manufacturing interferometers for optics metrology and software development. These items are sometimes referred to as non-recurring engineering cost (NRE).

Manufacturing costs include all costs associated with manufacturing one unit which can not be re-used for subsequent copies, for example the cost of polishing optics and acquiring CCD cameras.

System costs have been calculated based on manufacturing one unit and include the cost of design and infrastructure development.

Total price includes allowance for vendor mark-up, based on a percentage above and beyond the cost of manufacturing and shipping a single unit.

Labour costs have been calculated based on a personnel cost of $250,000 per annum per full time equivalent (FTE), this being the fully loaded cost of one FTE including overhead, G&A costs, etc., and will vary among vendors.

2.1 Notes on specific line items

Some of the line items are self-explanatory; however others require more detailed explanation, in particular with respect to the wide range of values quoted for certain components, for example the fabrication of optics. In general the cost of modifying or reusing existing designs and infrastructure is at the bottom of the range quoted, whilst a new design starting from a blank sheet is at the top of the range.

2.1.1 System design and infrastructure set-up

- Optical and mechanical system design includes the time of a lens designer to fully design and investigate one particular design for both illumination and imaging optics, and the engineering time required to design and specify mechanical hardware.
- System performance simulation allows time for performance of detailed aerial image calculations to demonstrate equivalence of the design with performance of an EUV scanner.
- Optical system metrology infrastructure: the range of values quoted here ranges from re-using or adapting existing interferometers, possibly based on spherical interferometers if the aspheric departure is sufficiently small, to designing and fabricating new interferometers for new aspheric elements at the top end of the range. There is a significant difference in effort required between these approaches.
- AIM Software development and System control software have wide ranges depending on what level of software exists for the vendor to use. Writing AIM analysis software from scratch could easily consume two programmers for a year, whilst modifying the existing AIM software for EUV could take significantly less time. Similarly, the range of values for system control software will depend on the extent to which existing control systems can be re-used in the context of an AIM tool.
- Certification of compliance: The AIM tool will have to be certified to meet SEMI and CE standards. This will take time to perform and must be budgeted for in tool development.

2.1.2 Manufacturing costs

- Manufacture and coating of imaging optics: The wide range of values quoted for optics manufacture represents the wide range of potential solutions. Manufacturing four new aspheric mirrors will be at the high end of the range, whilst it would be expected that re-using an existing design with an established manufacturing path (for example, but not limited to, the BEL optics) would be towards the lower end of the range. Similarly, the cost of mounting hardware will vary depending on the requirements of the particular optical design.
- Secondary magnification: Some designs require an additional secondary magnification stage, in the form of either a PEEM or visible light microscope.
- EUV Source: The requirements will vary depending on optical design and throughput. The range of costs included here is intended to cover the range from a solid target source, similar to that on the EUV reflectometer on the Low Defect Deposition system (LDD) at LLNL, to a more complex and powerful source like that used on the Sematech Micro-Exposure Tool (MET). Integration of the source will require a variable amount of labour depending on complexity of the integration task.
- Load-lock, stages, mask handling and mask chuck: cost will depend heavily on the level of automation and robotics employed. A manual loading system, similar to that in a scanning electron microscope (SEM), would be at the lower end of the range, whilst a fully automated system will necessarily be at the higher end of the range.
- Through-focus sensor: Some form of sensor is required to bring the mask into focus. This could be as complex as the image analysis system employed on the MET, or as simple as some cap-gauge proximity sensors.

2.1.3 Cost

This is the total of non-recurring and manufacturing costs from the above two sections and represents the cost of building, shipping and installing one system at the customer site. It does not include facility preparation at the customer site.

2.1.4 Price

The price charged for an AIM system will include vendor mark-up, which has been applied to the construction cost of a single system to arrive at a system price. We have chosen to apply mask-ups in the range of 15%-100% of anticipated cost, and have applied this separately to the upper and lower cost estimates arrived at above.

No specific line item allowance has been made for contingencies, however this might be inferred from the range of values quoted. A vendor may wish to increase line items to the high end of the range quoted to make allowance for contingencies; alternatively a vendor may choose to allow for contingencies by applying a higher mark-up.

2.2 Comments on the costing

2.2.1 Range of anticipated prices

The estimated system price given in the bottom two lines of the spreadsheet indicates a wide range of potential prices for an AIM tool. The estimated price range is from $3.3M at the low end to $14M at the high end, a very large range that at first glance would appear to be of little use. A significant factor in this mark-up range of 15%-100% applied to the system cost. This exaggerates the range of anticipated prices; it is therefore instructive to look at the cost range rather than price range to get an estimate of the actual cost to the vendor of building a tool.

For a system consisting of normal incidence, multilayer-coated optics the anticipated cost range is from $3M to $7M, a much smaller range which largely represents the difference in cost between re-using an existing optical set adapted for AIM purposes, as opposed to designing and constructing a dedicated optic set specifically for an AIM tool. As highlighted in the design report, re-using existing optics not specifically designed for AIM application, although cheaper, is expected to lead to some compromises in performance. We therefore anticipate that a cost-benefit trade-off may have to be made between system cost on the one hand and performance on the other.

We also note that no specific line item allowance has been made for contingencies, and that this may be inferred from the range of values quoted. A vendor may wish to increase line items to the high end of the range quoted to make allowance for contingencies; alternatively a vendor may choose to allow for contingencies by applying a higher mark-up. It may therefore be more realistic to take the high value of the 15% mark-up and the low value of the 100% mark-up as indicative of anticipated prices. This produces a range of prices from $5.7M to $8.1M, which is likely to be more representative of the anticipated price range for an AIM tool.

2.2.2 Difference in cost between multilayer and zone-plate systems

Zone plates are significantly cheaper to fabricate than multilayer-coated optics, and thus one would expect the price of a zone plate microscope to also be significantly cheaper than the price of a system using multilayer optics. We performed costing for both a zone plate and multilayer optics solution, as detailed in the attached spreadsheets. These costs indicate that the price difference between the two options, whilst evident, is not significant once other system costs are taken into account. This is because the cost of the optics, whilst significant in the case of multilayer optics, is nevertheless relatively small compared to other costs associated with constructing and integrating the whole microscope system. This is reflected in the relatively small difference in anticipated prices for the two types of system, as indicated in the costing.

3 Conclusion

It is expected that the cost of producing the first EUV AIM tool will be significantly higher than the cost of 193nm and 157nm AIM tools. This is due to the specific technical challenges associated with transitioning to EUV, in particular:

- Adapting existing visible light microscope platforms for use as an AIM tool is not an option for EUV. A new microscope must be designed from scratch, increasing the system cost;
- EUV systems require optics to be in vacuum, which adds hardware and complexity to the design; and
- The higher cost reflects the need to construct new optics and a new platform from scratch.

Although the difference in cost of optics makes a difference in price, this range of values caused by difference in optics cost is relatively small compared to the anticipated price. This is due to the high cost of developing and constructing other parts of the AIM microscope, of which the range of optics cost is relatively small.

Based on the itemised costing attached below, we estimate that the likely price range of an EUV AIM system is will be as follows:

	Likely range	Extreme range
Multilayer optics	$6 M to $9 M	$3 M to $14 M
Zone plate	$4.5 M to $6 M	$2.5 M to $10 M

For a system using normal-incidence multilayer coated optics is likely to be in the range of $6-8M, with possible ranges at extreme ends from $3-14M. If a zone plate solution is adopted the price is likely to be in the range of $4.5-6M with a possible range from $3-10M at the extreme ends of the scale. This difference in price reflects the difference in cost of optics fabrication between the two approaches, with the relatively small difference in price between multilayer optics and zone plate solutions reflecting the cost of elements common to both systems.

3.1 Disclaimer

The system costing presented in this report represents a best-guess estimate based on anticipated sub-system cost. This is in line with the nature of the costing anticipated in the statement of work and does not represent a quotation to construct a tool nor a collection of quotations from sub-system suppliers. In the absence of performing a full design of sufficient detail to enable a detailed cost analysis, it is difficult to be more precise about the costing. We have therefore chosen to present a range of values designed to encompass the anticipated range of approaches and corresponding costs feasible for satisfying the requirements of an AIM tool.

3.2 Auspices

This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48. The authors acknowledge funding from International SEMATECH under Project Lith 341. UCRL-CR-150028

4 Estimated costing for a system using multilayer coated optics

Multilayer coated optics

System design and infrastructure (one-off costs)

	Capital cost ($k)	Labor (person months)	Labor cost ($k/month)	Cost ($k)
Optical system design		1 to 2	20.8	20.8 to 41.6
Mechanical system design		3 to 6	20.8	62.4 to 124.8
System performance simulation		2 to 3	20.8	41.6 to 62.4
Optical system metrology infrastructure	100 to 800	2 to 8	20.8	141.6 to 966.4
System alignment infrastructure	100 to 200	1 to 4	20.8	120.8 to 283.2
AIM software development		6 to 24	20.8	124.8 to 499.2
System control software		6 to 12	20.8	124.8 to 249.6
Certification of compliance with SEMI/CE standards	0 to 50	2 to 4	20.8	41.6 to 133.2
Project management		4 to 6	20.8	83.2 to 124.8
Total one-off costs	200 to 1050	27 to 69		**761.6 to 2485**

Manufacturing cost (per unit)

	Capital cost ($k)	Labor (person months)	Labor cost ($k/month)	Cost ($k)
Manufacture of imaging optics, including coating	400 to 1000			400 to 1000
Manufacture of optical mounting hardware	50 to 150	2 to 6	20.8	91.6 to 274.8
Secondary magnification stage	0 to 300	0 to 6	20.8	0 to 424.8
EUV CCD camera	25 to 50			25 to 50
Optical system alignment		1 to 3	20.8	20.8 to 62.4
EUV source	500 to 1000	3 to 6	20.8	562.4 to 1125
Condenser, collector and debris shields	200 to 400	0 to 1	20.8	200 to 420.8
Vacuum hardware, load-lock	100 to 200	2 to 4	20.8	141.6 to 283.2
Stages, mask handling and mask chuck	200 to 400	1 to 3	20.8	220.8 to 462.4
Through-focus sensor	40 to 100			40 100
Vibration isolation	30 to 50			30 to 50
System integration and automation	80 to 100	3 to 6	20.8	142.4 to 224.8
Testing, burn-in and performance certification	to	2 to 4	20.8	41.6 to 83.2
Project management	to	6 to 12	20.8	124.8 to 249.6
Total manufacturing cost	1625 to 3750	20 to 51		**2041 to 4811**

System cost (for one unit)

	Capital cost ($k)	Labor (person months)	Labor cost ($k/month)	Cost ($k)
System design and set-up (from above)				762 to 2485
Manufacturing costs (from above)				2041 to 4811
Shipping, incl. insurance, customs, etc.	50 to 100			50 to 100
Installation and training at customer site		2 to 4	20.8	41.6 to 83.2
Total cost per unit, $k				**2894 to 7479**

Price (for one unit)

				Cost
Total cost (from above)				2894 to 7479
Mark-up	15%			434 to 1122
	100%			2894 7479
Total price per unit, $k	**With 15% mark-up**			**3328 to 8601**
	With 100% mark-up			**5788 to 14958**

5 Estimated costing for a zone plate system

Zone plate optics

System design and infrastructure (one-off costs)

	Capital cost ($k)	Labor (person months)	Labor cost ($k/month)	Cost ($k)
Optical system design		1 to 2	20.8	20.8 to 41.6
Mechanical system design		3 to 6	20.8	62.4 to 124.8
System performance simulation		2 to 3	20.8	41.6 to 62.4
Optical system metrology infrastructure		0 to 0	20.8	0 to 0
System alignment infrastructure	50 to 100	2 to 8	20.8	91.6 to 266.4
AIM software development		6 to 24	20.8	124.8 to 499.2
System control software		6 to 12	20.8	124.8 to 249.6
Certification of compliance with SEMI/CE standards	0 to 50	2 to 4	20.8	41.6 to 133.2
Project management		4 to 6	20.8	83.2 to 124.8
Total one-off costs	50 to 150	26 to 65		**590.8 to 1502**

Manufacturing costs (per unit)

	Capital cost ($k)	Labor (person months)	Labor cost ($k/month)	Cost ($k)
Manufacture of imaging optics, including coating	10 to 50	0 to 3	20.8	10 to 112.4
Manufacture of optical mounting hardware	25 to 50	1 to 3	20.8	45.8 to 112.4
Secondary magnification stage	0 to 0			0 to 0
EUV CCD camera	25 to 50			25 to 50
Optical system alignment		1 to 3	20.8	20.8 to 62.4
EUV source	500 to 1000	3 to 6	20.8	562.4 to 1125
Condenser, collector and debris shields	200 to 400	0 to 1	20.8	200 to 420.8
Vacuum hardware, load-lock	100 to 200	2 to 4	20.8	141.6 to 283.2
Stages, mask handling and mask chuck	200 to 400	1 to 3	20.8	220.8 to 462.4
Through-focus sensor	40 to 100			40 100
Vibration isolation	30 to 50			30 to 50
System integration and automation	80 to 100	3 to 6	20.8	142.4 to 224.8
Testing, burn-in and performance certification	to	2 to 4	20.8	41.6 to 83.2
Project management	to	6 to 12	20.8	124.8 to 249.6
Total manufacturing cost	1210 to 2400	19 to 45		**1605 to 3336**

Costs (for one unit)

	Capital cost ($k)	Labor (person months)	Labor cost ($k/month)	Cost ($k)
System design and set-up (from above)				591 to 1502
Manufacturing costs (from above)				1605 to 3336
Shipping, incl. insurance, customs, etc.	50 to 100			50 to 100
Installation and training at customer site		2 to 4	20.8	41.6 to 83.2
Total cost per unit, $k				**2288 to 5021**

Price (for one unit)

				Cost ($k)
Total cost (from above)				2288 to 5021
Mark-up	15%			343 to 753
	100%			2288 5021
Total price per unit, $k	**With 15% mark-up**			**2631 to 5774**
	With 100% mark-up			**4575 to 10042**